Nano-Imaging with Compact Extreme Ultraviolet Lasers

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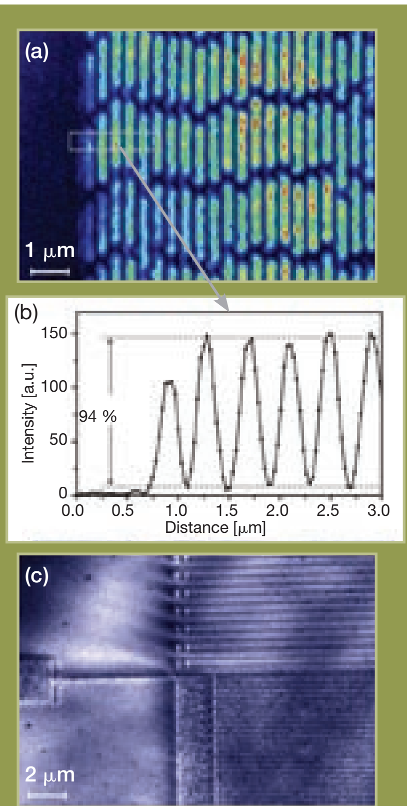
Recent advances in nanotechnology and nanoscience have created the need for new compact and practical imaging tools capable of resolving nanometer scale features. Although optical microscopy is unsurpassed in its versatility, the resolution of conventional optical microscopes is limited by the wavelength of the illuminating source to sizes that are typically larger than 200 nm. Short wavelength light has enabled optical imaging systems with significantly improved resolution. The best resolution so far—15 nm—has been obtained by imaging with 1.52 nm wavelength radiation from a synchrotron source.[1] Nevertheless, the widespread use of extreme ultraviolet (EUV) and soft x-ray microscopy requires the development of compact table-top systems capable of imaging at nanometer scales.



(a) EUV image of the edge of a zone plate with 200 nm outermost zone width obtained at 46.9 nm wavelength with a 10 s exposure; (b) The image cross-section shows that the 200 nm lines are well resolved by the microscope; (c) Reflection mode EUV image of a pattern of polysilicon lines on a silicon wafer obtained at 45° incidence angle with 20 s exposure.

We have shown that a high-resolution microscope based on a very compact high brightness Ne-like Ar capillary discharge laser emitting at a wavelength of 46.9 nm can rapidly render images in both the transmission and reflection modes.[2] In this microscope, the EUV light from the laser is focused onto a test sample using a Sc/Si multilayer-coated Schwarzschild condenser with a numerical aperture (NA) of 0.18. The magnified image of the sample is formed with a state-of-the-art free-standing zone plate of NA=0.12.

We recorded the images produced by the zone plate on a back-thinned CCD camera. Typical acquisition times were several seconds when the laser operated at 1 Hz with an output power of roughly 0.1 mW. The whole system is very compact and fits in a standard optical table. In the figure, part (a) shows an EUV image of the edge of a zone plate similar to that used as the objective lens. This image was obtained with a 10 s exposure time. The smallest 200 nm wide openings in the zone plate are clearly resolved, as shown by the 94 percent modulation in the image cross-section shown in (b).

Our analysis of the intensity modulation in these images demonstrated that the spatial resolution is in the range of 120-150 nm.[3] An increased resolution of 50 to 70 nm should be readily obtainable with this instrument by using zone plates with larger NAs.

We also operated the microscope in the reflection mode, which is needed to provide topographic information about material surfaces, microelectronic integrated circuits and nanostructures.[4] This mode of operation is more challenging due to the low reflectivity of materials at EUV wavelengths. Part (c) of the figure shows an image of a silicon wafer with a polysilicon line pattern that was obtained at a 45° incidence angle. At this angle, silicon's reflectivity at 46.9 nm is approximately 5 percent. Semi-isolated 100 nm lines can be discerned in this image, which was obtained with 20 s exposure time, whereas 250 nm lines are clearly resolved.

The use of high-average power table-top soft x-ray lasers in the 13 nm region[5] should result in even better, sub-50-nm resolution. This work was supported by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-0310717.

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References

1. W. Chao et al. Nature, **435**, 1210-13 (2005).
2. B.R. Benware et al. Phys. Rev. Lett. **81**, 5804 (1998).
3. G. Vaschenko et al. Opt. Lett. **30**, 2095-7 (2005).
4. F. Brizuela et al. Opt. Express **13**, 3983-8 (2005).
5. Y. Wang et al. Phys. Rev. A, in press.